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ABSTRACT

In this survey, an attempt is made to summarize the perspective on so-called 'misconceptions' research of those whose work in this field has not been guided by learning theory. Following the terminology of Driver and Erickson (1983), this research is called 'problem-oriented' in this paper. Its epistemological assumptions and assumptions about learning are identified: a key epistemological assumption is that a scientific or mathematical concept is characterized by a hard-core meaning on which experts agree and which students should master; and it is assumed that learning is influenced by instruction and by experience, including sensory experience. The long-term aim of many of these researchers is the improvement of instruction. Consequently the conclusions they have drawn have tended to focus on such issues as the ways in which aspects of instruction might unwittingly reinforce or promote 'misconceptions', and the development of alternative strategies. (Author)

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'Misconceptions' Research: A Problem-Oriented Perspective

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Introduction

My brief is to present the perspective on cognitive and conceptual change of those whose research in the field has not been undertaken under the banner of any particular learning theory. Rather than call it 'atheoretical', I prefer to adopt the term 'problem-oriented' which Driver and Erickson (1983) have used to characterise this kind of research; the 'problem' in this case is the presumed challenge to successful concept learning posed by the possession of 'misconceptions'. Research concerned with establishing the nature of spontaneous or intuitive theories held by students which has not been overtly guided by learning theory is considered here as a special case of problem-oriented research on 'misconceptions'.

Since this research owes no allegiance to learning theory, it is appropriate to ask whether the association with learning theory was consciously rejected and, if so, why; what, then, motivated the research; and what assumptions underlie it. I think it is fair to say that for many workers in this group, there was no conscious rejection. To some of them, proceeding from the standpoint of their own discipline - a science subject or mathematics, rather than education - it would simply not have occurred to see the matter in this way. To others, more actively aware that they are investigating learning difficulties, the question of whether their research ought to have been guided by appropriate theory was indeed relevant. Lazonby, Morris and Waddington (1982) complain by implication that theory-based studies are not 'pupil-centered'. Johnstone and Kellett (1980) perhaps speak for a number of this group when, in reporting on their researches on students' difficulties in chemistry, they say 'No particular theoretical stance was adopted lest the work should be prematurely coloured or skewed'. Underlying this concern about undesirable theoretical bias may be an attitude openly expressed by Arons (1985), in whose opinion no theory of learning has yet attained the status of a theory in the sense in which that term is used in science.

To the best of my knowledge, none of this group of researchers has gone quite so far as Chapman (1979) who, responding to a suggestion that only those aspects of 'psychological models' which have proved to be useful should be enlisted in the service of improving science education, says 'Why use the models in the first place? Especially when the preferred models offer nothing more than a codification of, and hence a strait-jacket to, common experience. One of the saddest developments of the past decade has

been the academisation of science education expertise. The reform of science education is not a difficult task. Trial and error, as practised by imaginative teachers sensitive to the classroom situation is all that is required. The task then is to disseminate - to use academically respectable jargon! - the results of their experience'. Perhaps our group of researchers might not wish to be identified with so extreme a viewpoint; but they might well acknowledge that in practice, their approach to instruction might conform pretty closely to that described in Chapman's summary: a kind of 'informed trial-and-error' strategy, in other words. In terms of such an approach, it makes sense to collect data with a view to feeding it back somehow into the educational process. It also makes sense to pay heed to 'the results of [other people's] experience'. Thus Arons (1985) strongly urges physics instructors to take advantage of the 'empirical results' of research into students' difficulties with physics. In her survey of research on conceptual understanding in mechanics, McDermott (1984) concludes with a section on 'implications for instruction' which contains recommendations on instructional practice and also stresses the importance of being aware of the results of this research. Implicit in this section seems to be the view that there is no need to be guided by any particular learning theory in order to make effective use of these results.

Motivation

By now, an answer to the second of my questions - what has motivated this research? - may have become evident. In the words of Doran (1972), introducing an early study of 'misconceptions' of selected science concepts, 'knowledge of common misconceptions related to science phenomena can be of extreme value to curriculum developers and classroom teachers'. A concern for improving instruction is a driving force behind much of the work being considered here. The initial stimulus for this concern may have come from one or more of a variety of sources. Awareness that students consistently make certain statements in a certain context, or commit certain kinds of error in solving standard problems, or are prone to certain confusions has clearly been the springboard for some of this research. As summed up by Trowbridge and McDermott (1980), 'Our interest in this type of research stems from the common experience of many instructors that certain conceptual difficulties occur frequently and predictably among introductory physics students'. Concern about the content of resource materials and its possibly deleterious effect on learning is another stimulus. It is the

common experience among college instructors to inspect a high-school (or middle or elementary school) textbook and find it wanting; when questionable or inaccurate assertions or arguments in such resources are echoed in students' work, one seems to have a problem worth pursuing - or so at least some researchers (e.g. Warren 1971, Helm 1978) have thought. A further stimulus relating to instructional concerns is the use within science or mathematics of everyday words whose technical and familiar meanings may differ markedly. (Cf. Duit (1983): 'Undoubtedly, the learning of concepts is substantially influenced by the everyday meaning of words like work, force, power and energy which are used as names for concepts in science. Becoming familiar with the meaning of such concept names before and after instruction, therefore, provides important information for lesson planning and evaluation'.) Research on students' spontaneous or intuitive theories, which forms an important subclass of the work under consideration here, seems to have been stimulated by students' responses to certain tasks; the researchers (e.g. Viennot 1979, McCloskey et.al. 1980, 1983 and Clement 1982) hypothesized from these responses that the students adhered to naive, spontaneous theories about the world about them, despite having been taught very different views.

Underlying Assumptions

Although this research is not guided by learning theory, it by no means follows that it does not rest on assumptions or hypotheses of some kind. It is thus reasonable to try to establish the actual underlying assumptions and to consider to what extent, if at all, these might have 'skewed' or 'colored' the research. These assumptions will be grouped under two main headings, namely epistemological assumptions and assumptions about learning.

(1) Epistemological Assumptions

Of key importance here is the question of what the researcher thinks a 'concept' is. That this is far from trivial is well illustrated by the recent survey by Gilbert and Watts (1983), who consider three views of a concept, called 'classical', 'actional' and 'relational' respectively, and classify various 'misconceptions' studies according to the view of the concept they are supposed to exemplify. My own examination of the research under discussion leads me to remark that, although none of its practitioners addresses the above question directly, they would probably agree that a

characteristic of a scientific or mathematical concept is that it has a hard-core meaning (I would prefer not to use the word 'definition') upon which 'experts' (as opposed to 'novices') in the discipline would agree; in other words, there is a 'consensus view' within the professional community of any given concept of interest. Trowbridge and McDermott (1980) talk of 'the understanding of a concept by members of the physics community' and point out that 'physics instructors generally share a common interpretation of the kinematical concepts based on operational definitions and precise verbal and mathematical articulation'; Johnstone, Macdonald and Webb (1977) refer to 'the concept of chemical equilibrium' in such a way as plainly to imply that their readers will have a common view of what 'chemical equilibrium' is; and Brumby (1979, 1984), in her studies of students' difficulties with natural selection, uses such phrases as 'the proportion of students who understood the concept of natural selection', 'several basic concepts in immunology were incorrectly introduced into these incorrect explanations' and 'several students... incorrectly implied a master-mind role for natural selection', all of which suggests that there is agreement amongst experts about what is 'correct' in such instances.

All of this is <u>not</u> to say that these researchers necessarily believe that all concepts of interest to them are capable of precise definition (in the strict sense of the term); that the meaning of a concept is totally conveyed by its definition, if such exists; that all experts 'define' the same concept in exactly the same way (Konold (1983), in his study of informal conceptions of probability, is at pains to describe the range of interpretation of probability to be found amongst probability theorists); and that even within the context of the same theory, the meaning of a concept may not change subtly over the years. It is perhaps necessary to emphasize this, lest I be thought by some to be saddling research workers with what Gilbert and Watts (1983) have called the 'classical view' of a concept. As they describe it, that view amounts to asserting that 'all instances of a concept share common properties and that these properties are necessary and sufficient to define the concept'; as they point out, such an 'all-or-nothing, syllogistic concept bears little resemblance to the rather messy actuality of conceptual activities in either science-subject-orientated terms, or in everyday life'. Our present group of researchers might be happy to accept the first half of the quoted statement setting out the 'classical' view, but not necessarily the second.

What is common to these researchers is the assumption that attainment of the consensus view of a given concept is a desirable outcome of learning - in other words, that students should master the meaning which experts ascribe to a concept. That raises the question of how such mastery, or the lack of it, is to be recognized: what criteria are to be set for deciding the extent of students' understanding of a concept. Some investigators are explicit about these. Brumby (1979) says 'Good understanding of natural selection was defined in terms of Bloom's higher levels of application and analysis'; in her later study (Brumby 1984) of misconceptions of natural selection amongst a different target group, she makes no direct reference to Bloom, but instead measures degrees of understanding (sound, partial or poor) in terms of numbers of problems 'correctly' explained in terms of natural selection. Trowbridge and McDermott (1980) adopt as a measure of understanding of a kinematical concept 'the degree to which an individual successfully applies that concept to the interpretation of simple motions of real objects'. Peters (1982) says that by 'understanding', 'We do mean that a student should be able to approach a physical concept from all directions, from the observable phenomena to the verbal, symbolic and mathematical representations of that concept. The student should be able to distinguish between closely related concepts, noting their similarities and differences'. From the kinds of tasks required of students in other investigations, it is clear that the researchers concerned adopted broadly similar criteria for concept understanding.

(2) Assumptions about learning

It is scarcely to be wondered at that plain statements of assumptions about learning are, on the whole, not to be found in the published accounts of problem-oriented research. Some, at least, of these assumptions can be deduced from the motivation of the research, if stated, or the discussion of its results. If a study was undertaken in the hope that it could lead to improvement in instruction, or if the paper describing it includes a section on 'Implications for Instruction', it is reasonable to conclude that those responsible believe that instruction influences learning. Such an assumption might be thought to be so self-evident as hardly to be worth mentioning; so it would be, if the links between instruction and learning were unproblematical. As some of this research has indicated, this is far from being the case. To be sure, Warren's complaint that the students he had encountered had 'received a garbled version of the idea of an inertial

force' (Warren 1971) suggests a model of learning which requires little or no activity from the learner beyond absorbing what is supposedly 'received'. But many authors neither adopt so straightforward a view nor suggest any clear alternative. Instead, they confine their reflections on the matter to the consideration of which feature(s) of the instructional process might be the most influential in the formation of a concept. Thus Cohen, Eylon and Ganiel (1983) suggest that some of the difficulties which students have in understanding electrical circuits may be connected with the sequencing of relevant topics in the curriculum, and according to Kinnear (1983), 'Students of genetics develop their understanding of genetic ratios and their concept of probability as it applies in genetics from a variety of sources, including participation in laboratory activities, problem-solving tasks and textbook readings'.

The other major assumption about learning which underlies much of this work, especially the 'important subclass' concerned with intuitive theories, is that learning is influenced by experience, especially sensory experience. Workers in the field have found it appropriate to stress the role of one or other of these influences when looking for possible sources of 'misconceptions'. If the student has, in Clement's words, 'intuitive preconceptions that he develops on his own before entering courses' (Clement 1982), then it may be natural to seek the origin of those preconceptions outside the realm of instruction. McCloskey (1983), noting the widespread adherence to an impetus theory of motion similar to that of the medieval philosophers amongst the students whose beliefs he investigated, was led to the view that 'the impetus theory is a natural outcome of experience with terrestrial motion'. An example of the perceived relevance of both of these influences on learning to the study of the same topic is provided by Murray (1983); in investigating students' misconceptions of osmosis, he concluded that 'intuitive conceptions of concentration and dilution can be acquired through everyday experience', whereas 'concepts of semipermeability are acquired through instruction in science'.

Methodology

A considerable range of methods has been used by 'problem-oriented' researchers to investigate students' views of concepts or the broader schemes ('theories', 'frameworks') of which these might form part. Multiple-choice questions, in which distractors embody suspected

misconceptions, were used in earlier studies (e.g. by Doran (1972), Duncan and Johnstone (1973) and Za'rour (1975)) and also in recent work (e.g. by Cohen et.al. (1983), Whitaker (1983) and Ivowi (1984)). Written tests incorporating free-response questions have played an increasing role in this research over the years; categories of these include the solution of qualitative and quantitative problems and the criticism of statements which may or may not be correct. Simple experimental or observational tasks have been given to students. Various forms of interview have been used, including the 'individual demonstration interview', a 'one-on-one discussion between a subject and a researcher about an observed physical system' (Goldberg and McDermott 1983). Researchers have not necessarily limited themselves to a single investigating technique, and many studies have used a combination of the methods mentioned; the administration of written tasks may be followed up with interviews with some of the subjects, for example. Most of this research has been done with high-school or first-year college students, but some studies have used elementary - or middle-school pupils on the one hand or graduate students and teachers on the other.

In some of the earlier studies, the authors (e.g. Doran (1972) and Za'rour (1975)) showed concern about the reliability (in the technical sense) of the tests they administered. The measures they used were derived from traditional item analysis and are thus inappropriate to tests which are not norm-referenced (cf. Helm 1978, 1980). Recent discussions of this issue have adopted a qualitative rather than a quantitative approach. Hoz (1983) has proposed various criteria for improving the reliability of the individual interview: McDermott (1984), emphasizing that 'More than in traditional scientific research, there is an active interplay among objectives, methods and results', has drawn up a list of characteristics of methodology which should be considered in interpreting the findings from a particular study. On such a basis, those interested can form judgments of the reliability and validity of the research.

Results

'Problem-oriented' research has been responsible for the identification and analysis of a considerable number of 'misconceptions" or conceptual difficulties in various disciplines. This is not the place to catalog these; instead, I shall concentrate on some important general results which have emerged. The first is the widely-noted finding that many

'misconceptions' are highly resistant to instruction; they are found to be alive and well amongst graduates and teachers of the subject. Another is that certain kinds of 'misconceptions' support the interpretation that they are manifestations of a more or less elaborate theory which the student has spontaneously or intuitively constructed. I have referred above to investigations of intuitive theories in mechanics. Brumby (1979, 1984) interprets the results of her studies of students' views of natural selection in terms of an underlying 'intuitive Lamarckism'. She suggests that this conception may be an 'extrapolation from changes seen within the lifetime of an individual to account for changes seen in populations over many generations'. Konold (1983) has shown that a significant number of students appear to operate with an informal theory of probability which he labels as an 'outcome-oriented approach to uncertainty'; that is, the approach of the student has the prediction of the outcome of an individual trial as its primary objective. In all of these cases, the intuitive theories are held by students who have received formal instruction in these topics. A further finding is that some 'misconceptions' are similar or identical to those found in instructional materials like textbooks, teachers' guides and test or examination papers. I would also like to emphasize what might be called a methodological result; that the value of asking qualitative questions about concepts in the case of quantitatively-oriented disciplines such as physics, chemistry or mathematics has been convincingly demonstrated. Students' answers to questions of this type have revealed significant aspects of their views of concepts which could not have been deduced from their solutions to quantitative problems.

Influence of Underlying Assumptions on Methodology

The variety of methodologies used in this research suggests that the underlying assumptions have not imposed any obvious constraint on the mode of investigation. A closer look reveals that many of the tasks used are similar or identical to those which form part of the instructional process. One might take this as confirmation that the research is dominated by an 'instructional' stance and by the consensus view of a concept (since tasks administered during instruction are intended to assess the extent to which that view has been acquired). This dominance may be real, but what is most relevant here is that it has not obstructed a detailed delineation of students'own views of a concept or the revelation that such views may be strikingly different from those taught. A limited view of a particular

concept may, indeed, limit the usefulness of a study of that concept. The interesting investigation by Lazonby, Morris and Waddington (1982) of high-school students' difficulties with the mole appears to adopt criteria for understanding this concept which relate only to the ability to solve numerical problems, so that one may yet feel that there is more to mastering the mole than their findings imply. Konold (1983) has pointed out that simply asking students to provide numerical probabilities in response to questions, as has been done in some studies, is an unsatisfactory way of trying to find out about students' informal probability theories; as he says, the students' responses cannot be easily interpreted if they derive from views which are inconsistent with formal theories.

Investigations of students' intuitive theories have sometimes prompted the search for methods of looking for links between experience and students' views. Having hypothesized that students construct impetus theories of motion on the basis of experience, McCloskey (1983) was faced with the puzzle that many students 'develop incorrect beliefs about the trajectories of moving objects... that apparently conflict with everyday experience'. His next step was to conjecture that these incorrect beliefs stemmed from misperceptions of motion, and to devise ways of finding out how accurate students' perceptions are. One may object that the implied connection between concepts and experience is unduly simple and by no means confirmed by McCloskey's further finding that students do indeed misperceive under certain circumstances (cf. Strike 1983). More important for our immediate purposes is the fact that research guided by the assumption that experience influences learning has yielded up results of interest.

The Problem-Oriented Perspective

The perspective represented by the research represented here is characterized by its motivation and underlying assumptions (including the lack of detailed assumptions about learning) and by the kinds of interpretations and conclusions which are drawn from it. As one might expect, the latter are influenced by the former. Since improvement of instruction is the long-term aim of the research, conclusions drawn have tended to focus on possible links between results obtained and aspects of instruction. Some workers have pointed to what they believe are identifiable sources of 'misconceptions' in instructional materials or methods; others, while noting the existence of specific misconceptions

revealed or confirmed by the research, have drawn attention to the broader consequences of these results - for example, that it is sound strategy to have students look closely at the implications of their own misconceptions. Since this research stands outside learning theory, its practitioners have not sought to justify any of the suggested links between the results and instruction in terms of a particular, detailed view of the process of learning. Instead, their collective standpoint seems to be that consideration of the results of the research can help practising teachers who are concerned about improving student learning, to cut some corners in working out their empirically-based approaches to the problem.

Value of the Research

Beyond its intrinsic interest, I believe the research reported on here has value for a number of reasons. Since much of it has been published in journals devoted to the disciplines, it has publicized students' conceptual difficulties amongst those professional scientists and mathematicians interested in the teaching of these subjects; in those same circles, it helps to maintain useful debate about logical and philosophical aspects of the teaching of various concepts; it has helped to convey the message that students' conceptual difficulties should be taken into account when planning instruction; and it has facilitated such planning by providing specific information about these difficulties in key concept areas.

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